Good Morning:

I am Dr.Kenneth Merckel President of the Michigan Steelhead and Salmon Fisherman Association.My interest in exotic species started in mid 1990's when G. Tracy Mehan III was director of the Office of the Great Lakes amd Mark Casscarilli was Envirormental Quality Analysist and whose assignment was stopping exotic species (NIS) invasion into the Great Lakes. Tracy moved on to Washington D.C. to a position with EPA dealing with NIS prevention.Mark Casscarilli moved on to Public Sector Consultant. Working together with many dedicated people the 2005 Michigan Ballast Water Bill was passed by the legislature and signed by the governor. This bill was necessary because the Federal Government was not able to pass any meaningful ballast water regulation to protect the Great Lakes.

I offer three reasons to maintain the present Ballast Water Bill without changes.

On Lake Huron we have felt the direct reaction between the introduction of exotic species (NIS) zebra and quagga muscles on our chinook salmon fishery. The first picture illustrates the Great Lakes before zebra and quagga mussels introduction.The food web with Diporeia(benithic invertabrate/zooplankton) which is at the bottom of the food web, alewives consume the diporeia and chinook a top line predator eats the forage fish alewives.

The second picture represents the introduction of NIS zebra and quagga mussels, which are filter feeders and the diporeia numbers declined.

The third picture illustrates alewive numbers impacted by loss of diporeia and predation by the chinook.

The fourth picture shows food web changes impacting the growth rate of chinook and the collaspe of the chinook fishery in 2005.

The economy of the Lake Huron Communities along the Lake Huron Shore changed drastically:

Marineas at Harbor Beach,Port Hope, Grindstone and Port Austin lost 90% of their dock rentals.

1. Concessionaire at Gridstone gave up 40 state docks, closed his marina and tackle store.

2. The Charter Boat Fleet Has been reduced by 90% of original number:

a. One charter boat at Lexington and 1 today

b 5 charter boats at Port Sanilac today 0

c One charter boat at Harbor Beach doing lighthouse tours where they had 5-7 fisher charters

d Gridstone had 15-20 charters and today 4 charters.

e 3 charter boats at Port Austin where there used to be 10

This has affected the econmy of the Thumb with closure of grocery stores, motels, bed and breakfast and many merchants that relied on the chinook fishery closed their doore when the chinook collasped

The next item is the appearence of another exotic species Illex illecebrouss (squid) which was found off Lakeport State Park, Sanilac County in June of 1998

On June 25th 1998 I received a call from a resident at Lakeport that stated that while swimming and walking in Lake Huron octopi-like creatures attaching to their legs and swimming away producing and inky substance . I told them to contact Jim Baker at the Bay City DNR and he sent a crew out on the 26th . People captured 3 specimens which were dead within 48 hours due to kidney failure from fresh water intake Death occurs within 24-48 hours. The samples were sent to the Fields Museum in Chicago for identification. Report included.

I called Sarmia Group Coast Guard because boats transiting Lake Huron must report in before entering or leaving Lake Huron. I asked for a vessel list from June 23 to 26th using the kidney failure time as a time line I found out the vessel was the up-bound Handy Laker passed the Port Huron cut bouy 1 and 2 at the had of the St. Clair River at 0110 local time June 24 with a cargo of steel bound for Chicago previous port of call before entering seaway was Mexico. The ship did a salt water ballast exchange in the Carribean Sea, Gulf of Mexico and blew ballast in Lake Huron off Lake Port Michigan. An example of salt water ballast exchange that doesn't work.

The third item is from he Journal of Applied Ecology 2012 titled"Role of Domestic Shipping in the Introduction or Secondary spread of non indiginous species; biologic invasion within the Laurentian Great Lakes" Report included.

Less the 1% of port operations in Michigan are from transoceanic vessels. Under the Obama Administration commercial harbors must handle 100 million tons of cargo per year to be considered for dredging .To my knowledge no Michigan harbor qualifies. With the Great Lakes water level approching near 1960 low water datum this will preclude increased transoceanic vessels on the Great Lakes.

Faced with these facts the Michigan Steehead and Salmon Fisherman's Association opposes any change or additions to weaken the 2005 Michigan Ballast Water Bill. It gives the Great Lakes the protection it needs to prevent additional exotic species introduction and does not compromise the 7 billion dollar Great Lakes fishery and the 12.8 billion dollar economy created by the Great Lakes.

Thank you for your time and I will answer any questionsthat you have.

Fisheries and Oceans Canada
Coast Guard
Central & Arctic Region

Pêches et Océans Canada
Garde côtière
Région du Centre et de l'Arctique

July 14, 1998
To: Doctor Kenneth Merckel
Via FAX
1-517-843-5778

Subject: Information on Salt-water vessels passages.

Dear Doctor Merckel,

Here is a list of the salt-water vessels during the period June 23rd, 1998 and June 26th, 1998. The vessels are either proceeding upbound or downbound on Lake Huron. These are the only foreign vessels on the dates you have provided me.

If you have any other question, please don't hesitate to call me at 1-519-337-6572.

Yours truly,

Pierre Papineau

Pierre Papineau
Officer-In-Charge
Canadian Coast Guard

Canada

June 23, 1998

Upbound – NIL

Downbound

M/V Federal Calliope passed Port Albert and Harbour Beach calling-in-point on Lake Huron at 0435 June 22 local time. The vessel had departed upper lakes port and had a cargo of limestone. She was bound for Montreal Que. (Previous port of call before entering Seaway – **United Kingdom – Britain)**

June 24, 1998

Upbound

M/V Handy Laker passed Port Huron Cut buoys 1 & 2 at the head of St. Clair river at 0110 local time with a cargo of steel, bound for Chicago. (Previous port of call before entering Seaway – **Mexico)**

Downbound - NIL

June 25, 1998

Upbound

M/V Gemini/3FBG7 (foreign vessel) passed Port Huron Cut buoys 1 & 2 at the head of St. Clair River at 0610 local time bound for an Upper Lakes port. The vessel's previous port was Toronto Canada with a load of sugar. (Previous port of call before entering Seaway – **Guatemala)**

Downbound

M/V Federal Fraser reported 30 minutes above Lake Huron Cut buoys 11 & 12 at 1222 local time with a cargo of grain bound for Montreal Quebec. The vessel had loaded the grain in Thunder Bay Ontario. The vessel left Thunder Bay Ontario on June 22, 1998 at 2033 local time. (Previous port of call before entering Seaway – **Belgium)**

June 26, 1998

Upbound - NIL

Downbound

M/V Regina Oldendorff passed 43° 10' North downbound Lake Huron at 0915 local time with a cargo of wheat bound for Montreal Quebec. (Previous port of call before entering Seaway – **Spain)**

M/V Stolt Aspiration passed 43° 10' North downbound Lake Huron at 1907 local time with a cargo of Tallow bound for Hamilton Ontario. (Previous port of call before entering Seaway – **Dublin)**

SQUID!

DEPARTMENT OF NATURAL RESOURCES

Notes and Reference Form

Waterbody: Lake Huron
TRS: Off County Line Rd (Fisher Rd.)

County: Sanilac/St.Clair
Date: June 26,1998

On the morning of Friday, June 26th, a call came in from a resident of the Lakeport Area regarding where to report exotic weird creatures. He then proceeded to explain how a neighbor had asked him to call regarding "her finding of what she believed to be octopi while swimming along the beach directly in front of Fisher Rd. –county line in Lake Huron." I took his name and number, Jerry Harrington (517) 327-6458, and he gave me directions to the residence where the alleged "Octopi" were. Cindy Neff (no TX) collected three dead ones the previous day (Thursday) and had them in a pail.

I arrived at her residence at 12:00pm on Friday, June 26, 1998, and she and another resident Tim Hills (810) 385-9806, told me that they collected the ones in the pail the previous day and that these were dead when they found them. They did say that there were live ones with them, and that if you dangled things in front of them, they would latch on for a second or two with their arms. They also saw them fill up, compress, and dart off. They estimated they saw 12-14 of them of various sizes. They said they collected these off the beach in water depths of 3-4'. They said that Cindy accidentally stepped on one, and dark pink ink came out. I witnessed a pink residue in the pail.

The creatures in the pail were not octopi, but rather some species of squid. They had a more tubular body, well-developed eyes, 10 legs (8 surrounding 2 longer modified ones); the fins came to a triangle at the posterior. They were pinkish-white in color, and the residents described them as kind of glowing.

I asked them to show me where these were collected, hoping to see or collect some live ones. Tim Hills went swimming and netted 2 additional specimens (also dead) which I took back and preserved in formalin. No live specimens were observed, and visibility was not as good as the previous day. I gave all the residents my card, and asked that they contact me if they collected any live specimens.

We sent the specimens to Dr. Janet Voight (mollusk expert) at the Field Museum in Chicago. She positively identified them as a midwater oceanic species which ranges in Gulf Stream waters from Florida to Iceland /British Isles, Illex illecebrosus. She stated that their systems could not handle freshwater, as their kidneys are not developed for it, so she didn't believe that they could survive. The specimens did exhibit swelling consistent with being in or on freshwater. This species is hard to keep in captivity. Both specimens were immature females.

According to Dr. Voight, the most likely vector to the Great Lakes was via ballast water of sea going vessels. The seafood industry does ship squid, but they are almost always shipped on ice.

We notified Mark Coscarelli, with the Office of the Great Lakes, to provide him with the details.

On Tuesday, June 30, the District 8 fishing crew made an additional attempt to collect squid by beach seining at the Sanilac/St. Clair county line. Strong thunderstorms and northeasterly winds hampered the effort, and none were found. To date, no live specimens have been collected. In addition, we notified the Lakeport State Park of our activities, and asked them to report additional sitings and collections to us if they should occur.

Written By: Kathrin Schrouder

Date: 07/02/98

To James Baker
Michigan Dept. of Natural Resources
fax 517-684-4482

From Janet Voight
Zoology
Field Museum of Natural History
fax 312 663-5792

Re: Lake Huron Squids

I have identified the two specimens as members of the squid family Ommastrephidae, specifically Illex illecebrosus. I have attached a short summary of the species biology from the 1984 FAO Species Catalogue Cephalopods of the World.

Additional references that you may find helpful are:

Roper, C. F. E., C. C. Lu & K. Mangold. 1969. A new species of Illex from the western Atlantic and distributional aspects of other Illex species (Cephalopoda: Oegopsida).

Northwest Atlantic Fisheries Organization Scientific Council Studies, Special Session on Squids, number 9, 1984.

Roper, C. F. E, C. C. Lu & M. Vecchione. 1998. A revision of the systematics and distribution of Illex species (Cephalopoda: Ommastrephidae). Smithsonian Contributions to Zoology #586 volume 2: 405-423. (This is so new that I haven't read it yet.)

Ron Odor at the Dalhousie University in Halifax, Nova Scotia (odor@ac.dal.ca) has maintained members of this species in captivity and might have additional information on aspects of their biology.

As we discussed, Field Museum will retain one of the two specimens for deposition in our collection; the second will be returned to you by first class mail. I will be away from the museum for the next several weeks, but will return the first week in August. If you have additional questions you are most welcome to ask. My collection manager, John Slapcinsky (312) 922-9410 ext. 577 or slapcin@fmnh.org, will be happy to help you if he can while I am away.

Thank you,

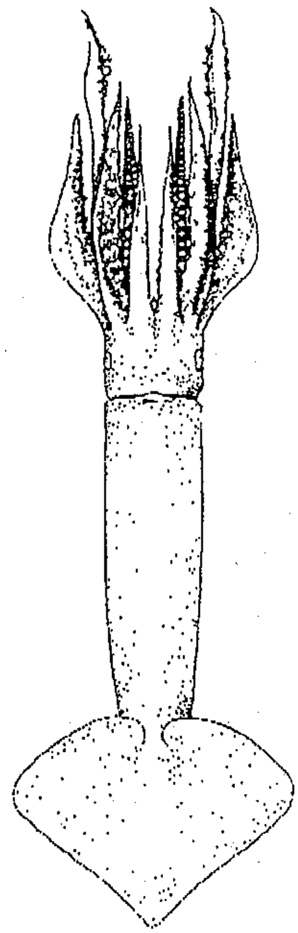
J. Voight

Janet Voight
Associate Curator
Zoology

Illex coindetii (Verany, 1839) | OMMAS III 1

Loligo coindetii Verany, 1839, Mem.Reale Accad.Sci.Torino, (2):94.

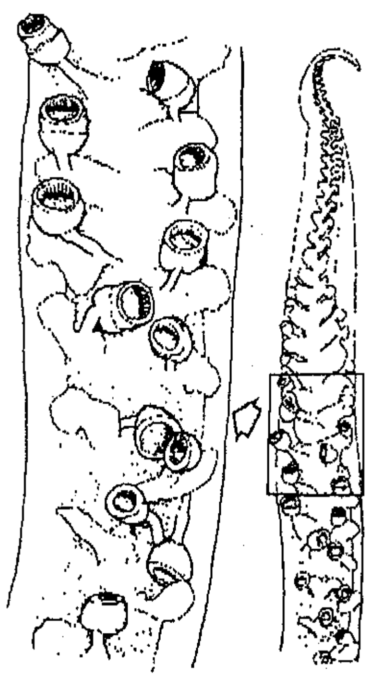
Synonymy: Loligo brogniartii Blainville, 1823; Loligo coindetii Verany, 1839; Loligo pillae Verany, 1851; Loligo sagittata Verany, 1851; Todaropsis veranyi Jatta, 1896; Illex illecebrosus coindeti Pfeffer, 1912.



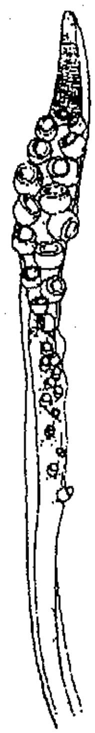
female
dorsal view

FAO Names: En - Broadtail shortfin squid
Fr - Encornet rouge
Sp - Pota voladora

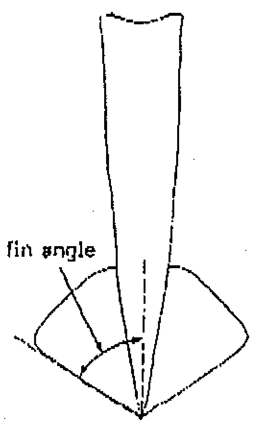
Diagnostic Features: Mantle widest at anterior end (except in fully ripe females), moderately long and narrow; tail pointed, moderately drawn out. Fin angle broad, exceeding 50° (100° in both fins), fin width greater than fin length. Head large and robust, especially in males, length about equal to width; funnel groove without foveola or side pockets. Dactylus of tentacular club with 8 longitudinal rows of small suckers. Arms very long, especially in males where second and third also are very robust; hectocotylized arm (in males) longer than the opposite ventral (IV) arm, its modified portion about 25% of arm length, distal trabeculae modified to papillose, fringed flaps; 1 or 2 knobs on dorsal row of lamellae of modified arm tip.



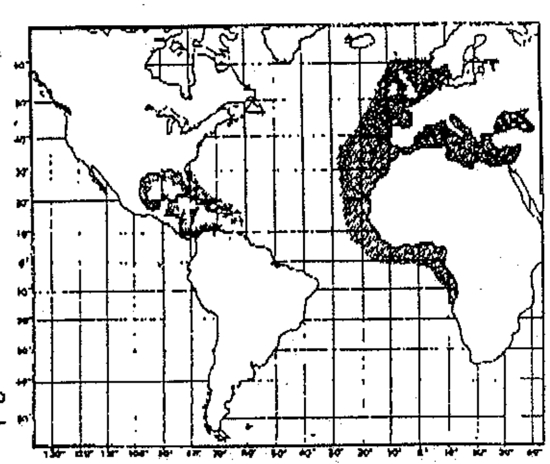
arm IV of male
hectocotylized



tentacular club



male, ventral view
of mantle and fins



Geographical Distribution: Eastern Atlantic: 15°S to 60°N, Mediterranean and Black Sea. Western Atlantic: Caribbean Sea, Gulf of Mexico and southeast Florida; 10°N to 27°N.

Habitat and Biology : A semidemersal, oceanic and neritic species occurring from the surface to about 1 000 m depth, common in the Caribbean between 180 and 450 m, in the western Atlantic between 200 and 600 m, in the eastern Atlantic between about 150 and 300 m, and in the Mediterranean between 60 and 400 m depth.

The squids are known to carry out diel vertical movements: they are associated with the bottom (usually muddy to silty grounds) during the day and disperse into the water column at night. They also migrate seasonally between deeper waters in winter and shallower waters in the summer. In the western Mediterranean, large mature or maturing individuals migrate towards the coast (from their overwintering areas in 200 to 400 m depth) where, at that time, temperatures tend to be cooler than in greater depths offshore. At an interval of several weeks, they are followed by smaller-sized squids that spend most of spring and summer in shallow waters, while migrating back to offshore areas in autumn. Two peaks can be distinguished during the extended spawning season, one in spring corresponding to the group of large sized individuals and one in autumn corresponding to the smaller sized group. Large females carry up to 12 000 eggs (diameter 1 to 2 mm), the number of eggs being a function of the size of spawners. Individuals hatching in summer usually participate in the autumn spawning in the following year while fall hatchlings tend to spawn in spring of their second year of life, this resulting in an alternation between the two major groups. Post-spawning mortality is high and the lifespan consequently ranges between $1\frac{1}{2}$ and 2 years. The species feeds on euphausid crustaceans and fishes; it is in turn preyed upon by tunas, rays, toothed whales and other larger carnivores.

Size : Maximum mantle length 37 cm in the northern part of its distributional range; 26 cm in females, and 22 cm in males off West Africa. Females grow larger than males. In the Gulf of Guinea, all females larger than 17 cm and males larger than 11.5 cm are mature. In the western Mediterranean, length at first maturity is 18.5 cm in females, and 11 cm in males.

Interest to Fisheries : Taken throughout the year in depths between 100 and 400 m in international bottom trawl fisheries in the western Mediterranean, off West Africa and Spain. Separate statistics are not reported, but it is believed that a sizeable portion of the 1981 catches reported in the FAO Yearbook of Fisheries (FAO, 1983) for Fishing Areas 34 and 37 (23 700 and 39 000 metric tons respectively) under the category "unidentified loliginids and ommastrephids" are attributable to this species.

Local Names : FRANCE: Faux encornet; ITALY: Totano volatore; JAPAN: Taiseiyoitekkususurume, Taiseiyosurume, Yoroppairekkusu; MALTA: Totlu hammari; MOROCCO: Passamas; SPAIN: Volador; USSR: Kalmas.

Literature : Mangold-Wirz (1963, biology, growth, western Mediterranean); Clarke (1966, biology); Fischer (ed., 1973, Species Identification Sheets, Mediterranean and Black Sea, fishing area 37); Zuzuki (1976, bycatch, Gulf of Guinea); Roper (1978, Species Identification Sheets, western central Atlantic, fishing area 31); Tomiyama & Hibiya (1978); Okutani (1980); Roper & Sweeney (1981, Species Identification Sheets, eastern central Atlantic, fishing areas 34/47 in part).

Illex illecebrosus (LeSueur, 1821)

OMMAS Ill 2

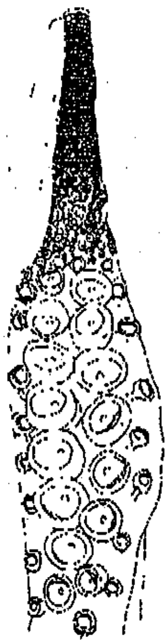
Loligo illecebrosus LeSueur, 1821, J.Acad.Nat.Sci.Phila, 2(1):95.

Synonymy : Illex illecebrosus illecebrosus (LeSueur, 1821); Loligo illecebrosus LeSueur, 1821; Loligo piscatorum La Pylaie, 1825; Ommastrephes illecebrosus Verrill, 1880.

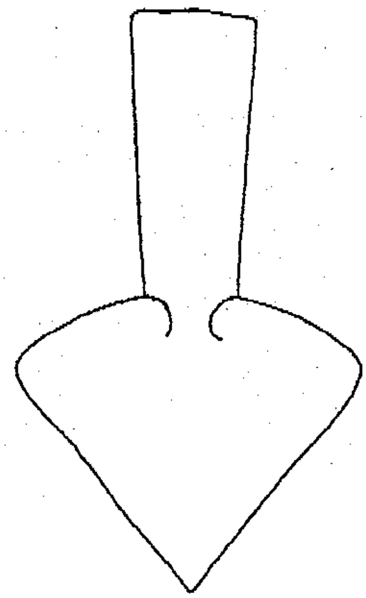
FAO Names: En - Northern shortfin squid
Fr - Encornet rouge nordique
Sp - Pota norteña

Diagnostic Features: Mantle robust, widest at midpoint between anterior end and beginning of fins; tail not sharply pointed. Fin angle moderate, 40° to 50°, mostly 45°; fin width greater than fin length. Head small, short and narrow. Arms relatively short, of about equal length in both sexes; hectocotylized arm (in males) shorter than the opposite ventral arm (IV), its modified portion very short, about 22% of arm length; trabeculae (lamellae) without papillose fringed flaps; 1 or 2 knobs on dorsal row of lamellae on modified arm tip. Colour: reddish-brown to deep purple, more intense on head, arms and dorsal surface of mantle and fins; paler on ventral surfaces; a brilliant yellowish-green tint.

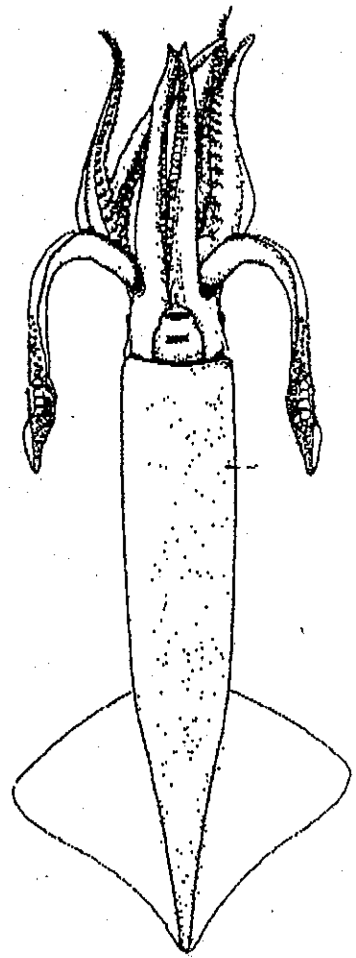
arm IV of male hectocotylized



tentacular club

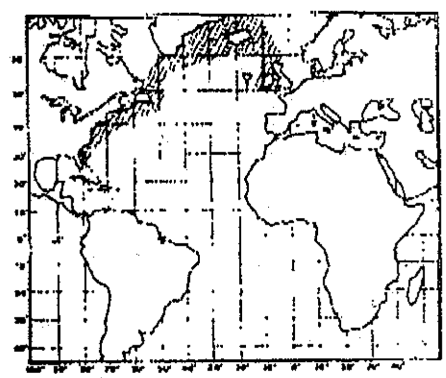


dorsal view of mantle and fins



ventral view

Geographical Distribution: Western Atlantic: 25°N to 60°N. Northern and eastern Atlantic: British Isles north to Iceland and Greenland.



Habitat and Biology: An oceanic and neritic species, its total depth range extends from the surface to about 1 000 m, but varies seasonally.

In the western Atlantic, seasonal northward - inshore and southward - offshore migrations take place in correlation with environmental conditions, feeding and reproductive cycles. Two groups of spawners one in spring/summer and the other in autumn/winter can be distinguished. Spawning apparently takes place offshore in deeper waters.

Females produce large, spherical, gelatinous egg masses that may reach 1 mm in diameter containing up to 100 000 eggs. Post-spawning mortality is very high. Fertilization of eggs is more efficient at higher temperatures (range 7 to 21°C). Eggs require temperatures between 12 and 22°C for complete development. Hatching occurs after 9, 13 or 16 days at temperatures of 21°, 16°, and 13°C respectively.

Larvae hatching from the winter brood between January and February grow to adult size in little more than 1 year, and spawn after approximately 18 months in summer. Summer hatchlings achieve a mantle length of about 18 or 19 cm after 1 year (females are slightly larger than males) and are ready to spawn in winter at an age of about 1½ years (Mesnil, 1977). Growth rates vary directly with temperature and inversely with size. Small-sized

Journal of Applied Ecology

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Role of domestic shipping in the introduction or secondary spread of nonindigenous species: biological invasions within the Laurentian Great Lakes

Elizabeta Briski[1*], Chris J. Wiley[2] and Sarah A. Bailey[1]

[1]*Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, 867 Lakeshore Rd., Burlington, ON, L7R 4A6, Canada; and* [2]*Transport Canada Marine Safety, 100 Front Street South, Sarnia, ON, N7T 2M4, Canada*

Summary

1. The most effective way to manage invasive species is to prevent their introduction *via* vector regulation. While progress has been made in the management of transoceanic ballast water, domestic vessels operating within smaller geographic regions such as the Laurentian Great Lakes, Mediterranean Sea, North Sea or Baltic Sea are often exempt from regulations.
2. We randomly surveyed unmanaged ballast water moved by domestic vessels within the Laurentian Great Lakes and compared the results with that of exchanged ballast water from transoceanic vessels to assess invasion risk of zooplankton transported by these two types of vessels.
3. Total abundance and species richness were significantly different between the two vessel types with mean abundance being two magnitudes greater, and species richness being three-fold higher in domestic vessels compared with transoceanic vessels. Abundance of restricted taxa – cumulatively the Great Lakes' indigenous and nonindigenous species (NIS) which do not occur in all five lakes – was also significantly higher in domestic vessels (mean densities were 24 170 and 3421 individuals per m^3 for domestic and transoceanic vessels, respectively), whereas the abundance of NIS did not differ between vessels (median densities of 2015 and 850 individuals per m^3, respectively).
4. We documented 89 species transported by domestic vessels of which 31 had restricted distribution and eight were NIS. While most NIS were already established in all five lakes, *Cercopagis pengoi*, a NIS of global concern, and *Nitokra hibernica* have not been identified from Lake Superior, and both were sampled from ballast water destined for discharge in Lake Superior. Beside the risk of spread of NIS between lakes, domestic shipping can act as a vector for homogenization of indigenous taxa, with at least 21 native species (99 events) being moved outside their historical distribution.
5. *Synthesis and applications.* Our study indicates that management of invasive species should consider ecological, not geographical or political boundaries. Domestic vessels operating within a limited geographic region have high potential to introduce or spread species with restricted distribution, demonstrating importance of intraregional ballast water management. Results presented here should interest policy makers and environmental managers who seek to reduce invasion risk.

Key-words: ballast water, domestic shipping, homogenization, invasion risk, management, nonindigenous species, zooplankton

*Correspondence author. E-mail: elizabeta.briski@dfo-mpo.gc.ca, elzabriski@yahoo.com

Introduction

The world's ecosystems are undergoing rapid changes, with the introduction and spread of nonindigenous species (NIS) being a key stressor on global biodiversity (Lawler *et al.* 2006; Clavero *et al.* 2009). Many species fail to establish after arrival to a new environment but those that succeed may have negative consequences on local community composition, ecosystem functioning and/or services to human society (Chapin *et al.* 2000). Such changes in the environment, coupled with low probabilities for eradication of established NIS populations, highlight the importance of early detection of introduced NIS and management efforts focused on preventing new introductions (Lodge *et al.* 2006).

The shipping industry has played a major role in the spread of aquatic NIS globally, with ballast water and sediment typically being more important vectors of introduction than hull fouling in the Great Lakes and possibly in other freshwater ecosystems (Sylvester & MacIsaac 2010). To prevent the introduction of new NIS, ballast water management regulations were enacted by the USA, Canada and many other countries (USCG 1993; IMO 2004; Government of Canada 2006; SLSDC 2008). All vessels arriving at the Great Lakes from foreign ports must perform mid-ocean ballast water exchange on filled ballast tanks and/or saltwater flushing on tanks with residual ballast, such that the final salinity of ballast water in tanks upon entering the Great Lakes is at least 30 parts per thousand. Several studies have demonstrated the high efficacy of these regulations for protecting freshwater ports from invasive species (e.g. Briski *et al.* 2010; Bailey *et al.* 2011). Nevertheless, 71% of ballast water transfers in the Great Lakes are exempt from regulations, being conducted by domestic vessels which may spread indigenous taxa or established NIS from one lake to another (Rup *et al.* 2010). Interlake ballast water transfers could be particularly effective at spreading species as domestic voyages are of short duration, with relatively high survivorship of species in ballast (DiBacco *et al.* 2012).

The Great Lakes–St. Lawrence River basin, however, can be divided into multiple watersheds resulting in at least five ecoregions: Superior, Michigan-Huron, Erie, Ontario and the Lower St. Lawrence (Abell *et al.* 2000). These ecoregions are characterized by distinct biodiversity, species endemism and community assemblages and consequently should be managed as separate conservation units (Abell *et al.* 2000). As a biological invasion occurs when any species arrives and establishes somewhere beyond its previous range (Williamson 1996), the translocation of native species with restricted distribution between adjacent ecoregions can also be considered a new introduction, even if at a finer scale than typically considered in invasion biology literature.

The objective of this study is to quantify the invasion risk posed by domestic ballast water transport considering movement of NIS as well as restricted taxa within the Great lakes (i.e. both indigenous taxa and NIS which do not occur in all five lakes are collectively referred to hereafter as restricted taxa). To parameterize the corresponding risk of introduction and/or spread, we compare the results of a random survey of zooplankton sampled from domestic ballast water with similar data from transoceanic vessels having conducted mid-ocean ballast water exchange (Bailey *et al.* 2011). Owing to shorter transit and no ballast water management for domestic vs. transoceanic vessels, we tested three *a priori* hypotheses: (i) zooplankton abundance is higher in ballast water of domestic vessels than transoceanic vessels, (ii) zooplankton species richness is higher in ballast water of domestic vessels than transoceanic vessels and (iii) finally, domestic vessels transport species with restricted distribution to locations from which they have not been reported.

Materials and methods

Between 2007 and 2009, we collected 83 ballast water samples from 72 domestic vessels operating between Great Lakes ports. Vessels were boarded opportunistically at cargo or fuel docks in Corunna, ON, Duluth, MN, Goderich, ON, Sarnia, ON, Superior, WI or Windsor, ON, to collect samples from a variety of source ports throughout the shipping season. In general, a single ballast tank was sampled during each vessel visit when all ballast was loaded at the same location. Three tanks with identical ballast history were sampled on four occasions to confirm similarity of community composition between tanks. In addition, on three occasions, two tanks having different ballast histories were sampled during a single vessel visit. We obtained data about each vessel's ballast history, including date and location of ballast uptake, from vessel personnel.

Tanks were sampled by two different methods. The preferred sample method was to lower a 30-cm-diameter, 53-μm mesh plankton net to the lowest accessible point of the ballast tank through an opened tank access hatch. One to five net hauls were conducted, dependent on haul depth, ensuring that a minimum of 1000 L of water were filtered through the net. When access through a tank hatch could not be obtained, 12·7-cm-outer diameter low-density polyethylene tubing, fitted with a stainless steel check valve, was lowered to the tank bottom through the tank's sounding tube. Fifty litres of water were collected by inertial pumping and filtered through 53-μm mesh. To determine whether differences in sampling methods may influence our results, four tanks were sampled using both methods. After filtration, each sample was preserved in ethanol and sent to taxonomic experts for enumeration and morphological identification. The status of identified taxa (native or NIS; broad or restricted distribution) was determined after extensive literature review.

STATISTICAL ANALYSIS

Statistical comparisons of total abundance and Sorensen's coefficients of similarity calculated for pairs of tanks sampled by different methods and for pairs of tanks within and between vessels indicated no effect of sampling method and confirmed similarity of tanks with identical ballast history (Appendix S1). Following these results, data from multiple tanks sampled during a single vessel transit were averaged and the sampling method was disregarded from further analyses. We compared community composition of unmanaged domestic ballast water with that reported by Bailey *et al.* (2011) for exchanged ballast water of transoceanic vessels. Bailey *et al.* (2011) sampled 24 ballast tanks from 16 vessels using net hauls with a minimum of 1000 L of water filtered through the net; methodology was similar to our study, allowing the two studies to be compared. We tested for differences in the cumulative mean abundance of total individuals, restricted individuals and individuals of NIS using the *t* test or Mann–Whitney *U*-test (SPSS 11.5.0; SPSS Inc., 1989–2002; Chicago, IL, USA). A logarithmic transformation was applied to all data sets to meet assumptions of parametric tests. If a Levene's test for homogeneity of variances was significant, or a normal distribution was not achieved, the nonparametric Mann–Whitney *U*-test was used. A significance level of 95% was used for all statistical analyses.

Species richness of the general vessel population, based on results from our sampled vessels, was estimated by calculating Chao-1, an estimator of species richness based on the number of rare species in a sample (Chao 1984; Chao & Shen 2003). We compared Chao-1 species richness estimates based on all taxa and on restricted taxa recorded from domestic and transoceanic vessels (Bailey *et al.* 2011) to examine the relative community diversity associated with the two vessel pathways. Sample-based species rarefaction curves were generated for both types of vessels to determine whether results were influenced by sample size. Confidence intervals (95%) were generated to test for significant differences between the two types of vessels (Chao & Shen 2006; Gotelli & Entsminger 2006). Chao-1 estimates were calculated using SPADE software (Chao & Shen 2006), while rarefaction curves were generated with 5000 random iterations using ECOSIM (Gotelli & Entsminger 2006).

Results

COMMUNITY COMPOSITION OF ZOOPLANKTON IN BALLAST WATER

Zooplankton abundance in domestic ballast water ranged from 460 to 1 344 200 individuals per m^3, with mean abundance (121 369 individuals per m^3) significantly higher than that reported previously from transoceanic vessels (5194 individuals per m^3; t test = 5·91, d.f. = 94, $P < 0·05$; Fig. 1; Bailey *et al.* 2011). While Copepoda and Rotifera each represented 37% of total abundance sampled from domestic vessels, followed by Cladocera (15%), Mollusca (10%) and other taxa <1%, Copepoda dominated samples taken from transoceanic vessels (97% abundance; Fig. 1). Rotifera were the most species-rich group sampled from domestic ballast water, with at least 54 species identified, followed by Copepoda (17 species), Cladocera (14 species), Mollusca (two species, only as veliger larvae), Amphipoda (one species) and unidentified Ostracoda (Appendix S2). In contrast, no Rotifera were found on transoceanic vessels; the most species-rich group was Copepoda (20 species), with all remaining taxa represented by <5 species per group (Bailey *et al.* 2011). The estimated species richness for the general vessel population was significantly higher for domestic vessels (117 species) than for transoceanic vessels (35 species; Fig. 2).

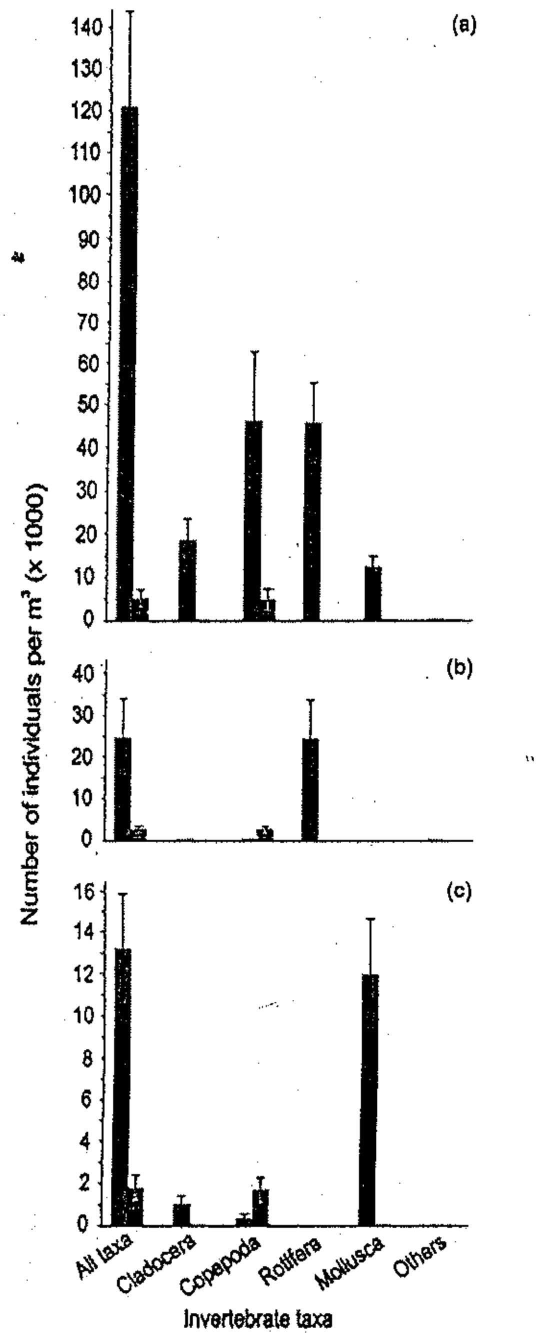

Fig. 1. Mean (±standard error) and median (horizontal line in bar) total abundance (a), restricted taxa abundance (b) and non-indigenous species abundance (c), by taxon in ballast water sampled from 72 unmanaged domestic (grey bars) and 24 exchanged transoceanic (black bars) vessels. Data for transoceanic vessels from Bailey *et al.* (2011). Note differences in scale of *y*-axes.

MOVEMENT OF SPECIES WITH RESTRICTED DISTRIBUTION IN THE GREAT LAKES

The mean abundance of restricted taxa was 24 170 and 3421 individuals per m^3 for domestic and transoceanic

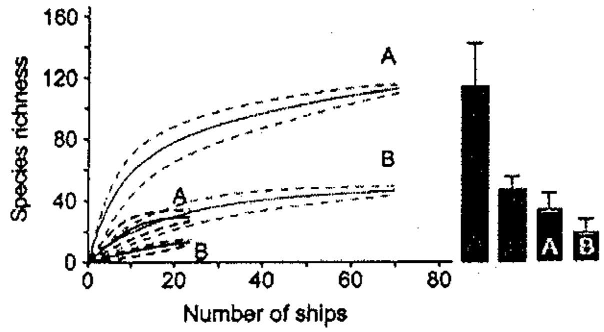

Fig. 2. Sample-based rarefaction curves for 72 domestic (grey lines, ±95% confidence interval) and 24 transoceanic exchanged vessels (black lines, ±95% confidence interval). Also shown are species richness estimates (Chao-1 ± 95% confidence interval) for domestic (grey bar) and transoceanic exchanged vessels (black bar). (a) All taxa and (b) restricted taxa, respectively. Data for transoceanic vessels from Bailey *et al.* (2011).

vessels, respectively (Fig. 1). Although mean abundance of restricted taxa in domestic vessels was significantly higher in comparison with transoceanic vessels (t test = 2·46, d.f. = 94, $P < 0{\cdot}05$; Fig. 1), NIS abundance was not different (Mann–Whitney U-test, $Z = -1{\cdot}24$, d.f. = 94, $P > 0{\cdot}05$; Fig. 1). The median abundance of NIS in domestic and transoceanic vessels was 2015 and 850 individuals per m^3, respectively (Fig. 1).

The estimated species richness of restricted taxa in the domestic vessel population (48 species) was significantly higher than that for transoceanic vessels (20·5 species; Fig. 2). In addition, 88% of restricted taxa in domestic vessels were Rotifera (27 species; Table 1; Fig. 1), while restricted taxa in transoceanic vessels were dominated (99%) by Copepoda (Bailey *et al.* 2011). Sixty-eight per cent of the restricted taxa in domestic vessels have not been previously reported from Lake Superior, 40% from Lake Ontario and 26%, 24% and 22% from Lakes Huron, Michigan and Erie, respectively. At least 18 species (59 events) were recorded in ballast water originating from lakes where those species had not been previously reported, while 23 species (101 events) were recorded from ballast water destined to be discharged outside of their historical distribution (Table 1).

Despite similar abundance of NIS between the two vessel types, the taxonomic composition was represented by different taxonomic groups. NIS in domestic vessels were mostly represented by Mollusca (92%, i.e. *Dreissena polymorpha* and *Dreissena rostriformis bugensis*, Fig. 1; Table 2), while Copepoda overwhelmingly dominated NIS in transoceanic vessels (99·9%, Fig. 1; Bailey *et al.* 2011). The cladoceran *Cercopagis pengoi* and copepod *Nitokra hibernica* were the only two NIS reported from domestic vessels which have not yet established populations in all five of the Laurentian Great Lakes. Only one of fourteen NIS sampled from transoceanic vessels, the euryhaline copepod *Acartia tonsa* was considered high risk for establishment in the Great Lakes (Bailey *et al.* 2011).

Discussion

Domestic vessels on the Great Lakes transport a higher abundance of zooplankton in unmanaged ballast water, by two orders of magnitude, compared with transoceanic vessels arriving with exchanged ballast water. Confirming our expectations, we found that the diversity of zooplankton was significantly greater for the domestic vessel population than for transoceanic vessels. We sampled at least 89 taxa in domestic ballast water of which 31 had restricted distribution in the Great Lakes and eight were NIS. As the total volume of ballast moved by domestic vessels is more than three times greater than the volume moved by transoceanic vessels in the Great Lakes (Rup *et al.* 2010), they represent a tremendously important vector for transfer of species within and between the Great Lakes.

While most NIS reported from domestic ballast water were already present in all five lakes at the time of our study, *C. pengoi*, a harmful NIS of global concern (ISSG 2011), and *N. hibernica* are not established in Lake Superior; as both species were sampled from ballast water destined for discharge in Lake Superior, domestic ships are clearly a vector for transfer of established NIS within the region. The high abundance and occurrence of the other NIS, particularly *Dreissena* spp., provides significant support for this finding, although the already widespread distribution of the remaining NIS prevents definitive conclusions on the role of domestic ballast water in their spread. Nevertheless, the continuing transfer of NIS already broadly distributed is concerning as mixing distant populations may provide opportunities for novel genetic recombination and evolutionary shifts in key life-history or morphological characters, which may result in unexpected surges of NIS population abundance and harmful impacts (Lockwood, Cassey & Blackburn 2005).

In addition to the secondary spread of NIS to new areas, domestic shipping can act as a vector for introduction or spread of indigenous species with restricted distribution to new locations. We recorded at least 23 native species (101 events) being moved to new locations outside their historical distribution, potentially resulting in new introductions to Lakes Superior, Huron and Erie. Although commonly referred to as a single ecosystem, diversity and community composition differ among the five Great Lakes (Abell *et al.* 2000) and introduction or spread of species from one lake to another could have negative ecological and economical consequences (Chapin *et al.* 2000; Lawler *et al.* 2006; Clavero *et al.* 2009), even if species are not spread far from the native region (Cullingham *et al.* 2011). Most restricted taxa found in domestic vessels were Rotifera, which until now are reported as NIS only in Italian and Polish inland waters (Gherardi *et al.* 2008; Ejsmont-Karabin 2011) and are not listed as notorious invaders. However, it is challenging to predict which species may become problematic owing to the context-dependent nature of invasions (Ricciardi, Palmer & Yan 2011).

Table 1. List of restricted species transported outside their historical distribution in the Great Lakes by domestic ballast water transits

Taxon	Ballast water source S	H	E	O	Mean abundance (No. m^{-3})	Ballast water recipient S	H	E	Mean abundance (No. m^{-3})
Cladocera									
Daphnia longiremis	–	–	–	–		2	–	–	1847·90 ± 1573·09
Cercopagis pengoi	–	–	–	–		1	–	–	0·30
Copepoda									
Nitokra hibernica	–	–	–	–		1	–	–	886·77
Skistodiaptomus reighardi	–	–	–	–		1	–	–	7171·21
Rotifera									
Anuraeopsis navicula	–	–	–	–		1	–	–	265·00
Anuraeopsis sp.	–	–	–	1	413·33	1	–	–	413·33
Asplanchna herricki	1	–	–	–	24 933·33	2	–	–	12 603·33 ± 1233·00
Brachionus bidentatus	–	–	–	1	135·29	–	–	–	
Brachionus budapestinensis	–	–	–	–		–	2	–	525·41 ± 474·31
Brachionus havaenensis	–	–	1	–	633·45	1	–	–	633·45
Brachionus quadradentatus	–	–	3	–	979·68 ± 302·94	–	–	–	
Brachionus urceolaris	–	–	2	–	1199·39 ± 300·19	–	–	1	83·80
Cephalodella sp.	–	–	–	1	1880·00	–	–	–	
Colurella unicata	–	–	1*	–	146·19	1*	–	–	146·19
Conochiloides dossuarius	1	–	–	–	264·10	–	–	–	
Encentrum sp.	–	1	–		2·34	–	–	–	
Euchlanis alata	–	–	–	1	135·29	1	3	–	1572·92 ± 1347·87
Euchlanis calpidia	–	–	1*	–	166·15	1*	–	–	166·15
Hexarthra mira	–	–	–	–		1	–	–	275·82
Kellicottia bostoniensis	–	–	6	–	242·36 ± 107·19	8	1	–	1265·19 ± 936·77
Keratella cochlearis robusta	2	–	3	–	340·70 ± 121·75	2	3	1	284·55 ± 114·17
Keratella cochlearis tecta	–	–	10*	4*	2968·84 ± 1453·72	5*	7*	2*	2968·84 ± 1453·72
Keratella taurocephala	–	1*	1*	–	12·70 ± 6·40	1*	1*	–	12·70 ± 6·40
Keratella valga tropica	–	–	4	–	1826·00 ± 1169·88	1	4	–	1487·86 ± 967·22
Lepadella ovalis	1*	–	3*	1*	135·76 ± 94·94	2*	1*	1*	135·76 ± 94·94
Lepadella sp.	–	–	1*	1*	6854·00 ± 6494·00	2*	–	–	6854·00 ± 6494·00
Notholca acuminata	–	–	–	–		1	–	–	4544·00
Notommata sp.	–	–	–	–		–	1	–	224·80
Platyias patulus	–	–	–	–		1	–	–	633·45
Polyarthra remata	3	–	–	–	8517·74 ± 4150·48	13	–	–	42 603·85 ± 36806·39
Polyarthra vulgaris	6	–	–	–	2448·43 ± 1355·56	22	–	–	12 323·39 ± 5855·61
Pompholyx sulcata	2	–	–	–	173·64 ± 24·75	3	–	–	416·83 ± 334·93
Synchaeta kitina	3	–	10	5	8240·16 ± 4091·36	2	–	4	17 181·29 ± 11630·90
Synchaeta pectinata	4	–	–	–	5561·23 ± 2662·21	13	–	–	5671·57 ± 3864·70
Trichocerca longiseta	–	1	–	–	50·68	3	1	–	1246·71 ± 676·67
Trichocerca rattus	–	–	–	–		1	–	–	233·30

The number of vessel events moving species from or to a location where not previously reported from is denoted in the ballast water source and ballast water recipient columns, respectively, including mean (±standard error) abundance per m3 sampled. Lakes are: S, Superior; H, Huron; E, Erie and O, Ontario. The * indicates uncertain cases. Historical distribution of species based on extensive literature review, including >60 scientific journal publications, taxonomic keys, and unpublished data reports (K. Bowen and O. Johannsson, Fisheries and Oceans Canada) spanning 1894–2011; a list of references consulted is available from the authors on request.

Considering the long history of ballast movements within the Great Lakes, the continued existence of restricted taxa suggests that intrinsic physical or chemical variability between lakes may prevent the establishment of some species in different parts of system (Grigorovich *et al.* 2003); however, even after many years of introduction, we would not expect all species which have the potential to establish to have successfully done so owing to long lag-phases and sampling bias, environmental and demographic stochasticity, as well as insufficient genetic diversity to allow for adaptation (Grigorovich *et al.* 2003; Lockwood, Cassey & Blackburn 2005). Notably, this study reported 18 species (59 events) in ballast water taken from locations where those species have not previously been reported. While it is likely that this finding is confounded by incomplete historical records of species' distributions, our literature review possibly overestimates species' ranges as reports were compiled on a lake-wide basis. Alternatively, it is possible that the individuals in question may have been loaded into tanks at a prior port of call and persisted for multiple voyages; however, the densities of restricted species in this study are at least one order of magnitude greater than the total abundance of invertebrates previously reported in residual ballast water

Table 2. List of nonindigenous species recorded in domestic ballast water samples

Taxon	Common Name	Mean Abundance (No. m^{-3})	Occurrence (%)
Cladocera			
Eubosmina coregoni	Waterflea	2603·73 ± 405·97	27 (37·50)
Bythotrephes longimanus	Spiny waterflea	7·41 ± 2·80	7 (9·72)
Cercopagis pengoi	Fish-hook waterflea	0·30	1 (1·39)
Copepoda			
Eurytemora affinis	Calanoid copepod	1861·91 ± 1394·94	12 (16·67)
Nitokra hibernica	Harpacticoid copepod	886·77	1 (1·39)
Amphipoda			
Echinogammus ischnus	Amphipod	15·18 ± 4·82	1 (1·39)
Bivalvia			
Dreissena polymorpha	Zebra mussel	9657·29 ± 2584·66	56 (77·78)
Dreissena rostriformis bugensis	Quagga mussel	6986·28 ± 1603·40	46 (63·89)

Mean abundance (±standard error), when present and occurrence in 72 vessels are provided. All taxa are considered established in all five Great Lakes except *C. pengoi* and *N. hibernica*, which are not reported from Lake Superior.

(Duggan *et al.* 2005). A third and very plausible explanation for species reports from new locations is that interlake spread of some restricted taxa has already occurred.

MANAGEMENT IMPLICATIONS

Low probabilities for the eradication of established NIS populations as well as millions of dollars spent annually on eradication programmes highlight the importance of management efforts focused on preventing new introductions and early detection of introduced NIS (Lodge *et al.* 2006). Our comparison of zooplankton abundance and species richness in unmanaged domestic ballast water and foreign exchanged ballast water indicates that unmanaged domestic vessels currently pose the greater risk for species invasions. The risk of unintentionally introducing new species could therefore be reduced through ballast water management of all ships, independent of operational area. In the future, ballast water regulations, as well as management of other vectors of invasive species, should consider ecological, not geographical or political boundaries. Recognizing that current requirements for ballast water exchange cannot be met by vessels operating intraregionally, it will be important to develop effective treatment technologies, such as filtration, deoxygenation and/or ultraviolet treatment, which could be utilized onboard vessels. Results presented here should interest policy makers and environmental managers who seek to reduce invasion risk, as well as shipping industry.

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